PERFORMANCE CHARACTERISTICS OF PLANNING ACTORS

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ABSTRACT. Planning is a field of interest in many scientific disciplines. These scientific areas cover a multitude of planning approaches that at first sight do not have much in common: psycho-physiological analyses, organizational science, linguistics, cognitive science, operations research, and spatial science, to name just a view. The differences in ontologies and methods used make it difficult to make statements that transcend the mono-disciplinary perspectives. Still, no matter the research field, planning always concerns anticipating on the future and determining courses of action. As a consequence, there must also be similarities between the various approaches that deal with planning. This paper proposes a number of characteristics that can be used to analyze the differences and similarities in performance of different kinds of planning actors.

1. INTRODUCTION

Where will we go and how do we get there? This question is an inherent part of intelligent systems. The ability to anticipate and plan is usually seen as a required and perhaps even essential feature of such systems. It is the fundament of goal directed behavior; systems that pursue goals need to take the future into account.

Planning is not a nicely ordered and well-defined subject. Various disciplines with various scientific backgrounds deal with planning, such as (cognitive) psychology, mathematics, economics, operations research, artificial intelligence, and management and organization. In our opinion, comparing, combining, or even integrating the research efforts of each of the individual planning approaches can be a fruitful next step in planning research in general. Due to the sheer differences between these scientific areas, however, it seems difficult to make generic statements about the relation between the planning of an actor and its performance. But, the fact that planning always concerns anticipating on the future and determining courses of action might provide an opening. This notion is used in this paper to introduce a frame of reference for planning. In section 2, we provide a generic and abstract definition of planning, resulting in a discussion of four different scientific planning areas. Section 3 provides a number of generic characteristics with which the planning research areas are compared. In section 4, we draw the conclusions.

2. PLANNING ACTORS

As stated in the previous section, many research areas somehow deal with planning. In this section, we will describe four of such areas. This description will be based around our conception of planning, which can be outlined by four topics.

First, it is important to acknowledge that some entity must make the plan. Note that all kinds of entities can make plans, for example, humans, robots, computer programs, animals, organizations, etc.

Second, someone or something must execute the plan, i.e., the intended future must somehow be attained. Again, this can be done by all kinds of entities, and the planning entities need not necessarily be involved in plan execution themselves.

Third, the planning entity needs some kind of model of the future, since the future is essentially non-existent. This model should include states, possible actions of the executing entities and the effect of actions on the state they reside in, constraints, and goals. Planning and anticipation presume that such a predictive model is available, otherwise the chance that a plan can be executed as intended becomes a shot in the dark.

The *fourth* element of planning is the plan itself. The plan signifies the belief that the planning entity has in the model of the future: the actions in the plan (which are performed by the executing actor) will lead to the desired or intended future state.

The first and second topics lead to four kinds of planning actors that have their own embedding in literature:

1. Humans that plan and execute: (cognitive) psychology
2. Humans that plan but do not execute: organizational science
3. Artificial actors that plan and execute: artificial intelligence
4. Artificial actors that plan but do not execute: operations research

In the remainder of this section, we will discuss these four kinds of planning actors. The third and fourth topic can be used to analyze the performance of planning actors. This will be discussed in the next section.

Humans that plan their own activities: To have a closer look at the execution of the task, we start with cognition, where the study of planning contains the study of human (intelligent) activities (tasks). In this perspective the old definition of Miller, Pribram & Galanter is used, saying that a plan is a hierarchical process within an organism that controls series of

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**
4. TITLE AND SUBTITLE **Performance Characteristics of Planning Actors**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Groningen,Faculty of Management and Organization,P.O.Box 800,9700 AV Groningen, The Netherlands,**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **Proceedings of the 2002 Performance Metrics for Intelligent Systems Workshop (PerMIS -02), Gaithersburg, MD on August 13-15, 2002**		
14. ABSTRACT **see report**		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

operations [1]. Jean-Michel Hoc elaborates this definition and says that planning always involves anticipation and schematization [2]. What he means is that planning is a two-line parallel process, in which a future state is taken into account (anticipation) and in which a (stored) mental scheme can be applied if a concrete planning problem arises. Therefore, Hoc talks about bottom-up and top-down processes that are always involved in making a plan.

Because of the terminology he uses, Hoc is implicitly taking a position in the complex cognitive debate about planning. This debate involves two closely related topics. The first deals with the question whether planning is a form of problem solving [3] or whether planning and problem solving only overlap [4]. The second is about the question whether human planners work hierarchically [3] or whether they plan opportunistically or even chaotically [5]. We discuss the issues successively in greater detail.

Planning and problem solving: Newell et al. [6] describe the planning method as a part of a general problem solving technique. It consists of a reformulation of the problem in more abstract and restricted terms, its solution in a simplified problem space with another level of resolution [7], its retranslation into the original problem situation and subsequently its solution. In later papers Newell & Simon rename the planning method as problem abstraction, necessary if the problem is not solvable within its original state space [3]. Because planning as well as problem solving means searching for routes (i.e., sequences of actions that lead to a solution or a goal state), the explicit distinction between planning and problem solving disappears in the later work of Newell & Simon. Planning is just one very interesting example of the general problem solving approach. Das et al. [4] argue against this "planning is a subset of problem solving" approach in saying that a difference exists in problems to prove and problems to find. According to Das et al. [4, p. 40] "planning is a more pervasive, general regulating process than problem solving, with problem solving being a part of a planning process." Planning includes anticipation and overview and refers to future actions, whereas these components seem to be absent in problem solving. According to us this may almost be a game with words, because one could state that searching and trying to reach a goal and constructing a problem space with states and operators, imply future actions and anticipation. We will not settle the discussion, here. Das et al., however, may have a point in one aspect of this debate. An enigmatic element in the problem solving approach of Newell & Simon has always been the starting point of the problem solving process. How does a problem solver construct a problem space? Where does the choice for a particular problem space come from? Why does a problem solver constructs this special problem space and not another? In terms of Newell & Simon the question is how a task environment gets its representation in a state space description. It is easy to say that one has a new problem here, which requires a second order state space description. Although this might be true in the strict sense of the word, it does not solve the issue. Perhaps something like what Das et al. called "overview" or "having a higher perspective" is necessary [4]. Therefore, it might be insightful to distinguish planning as second order problem solving from "ordinary" problem solving. If, in line with Newell & Simon, one considers the planning task in organizations and institutions to be a problem solving process, the question appears how planners construct an initial representation. Do they start with an overview or are they just trying? In the first situation there is an explicit state space to start with. In the second situation the state space is reformulated again and again.

Hierarchical and opportunistic planning: The discussion about the relation between planning and problem solving is closely connected to the way the planning (or problem solving) procedure is carried out in practice: hierarchical, opportunistic, or even chaotic. In the first place because the suggestion may be present that solving a problem with or without an overview is done straightforward. One just has to follow a couple of rules from top to bottom and one ends up with a solution. In the second place the issue of the overlap between planning and problem solving very much depends on the format of representations in the information processing system of the human planner. Do planners use production rules? How are these rules controlled? Or do planners use schemata and frames? Both issues come together in the discussion started by Hayes-Roth & Hayes-Roth [5] about hierarchical and opportunistic planning.

Hierarchical planning means that there is a nested number of goal and sub-goal structures or a hierarchy of representations of a plan. The highest level in the hierarchy may be a simplification or an abstraction, whereas the lowest level is a concrete sequence of actions to solve (a part of) the planning problem. One solves a planning problem by starting at the highest level and then one continues by realizing sub-goals until one reaches the final solution. Hayes-Roth & Hayes-Roth relate this to a distinction in the overview and the action aspect of plans that they successively call plan-formation and plan-execution [5].

Unjustly, but quite understandably, the hierarchical approach is attributed to Newell & Simon. They started to talk about problem solving in terms of problem spaces, goal hierarchies, and universal sub-goaling. We consider this attribution to be at least partly wrong - one only has to recall Simon's bounded rationality concept - but we are not going to discuss the issue here [8].

In a contradistinction to the hierarchical view on planning, Hayes-Roth & Hayes-Roth propose a so called opportunistic approach to planning. This non-hierarchical planning assumes that a plan is created with the help of some kind of mental blackboard where pieces of information, relevant cues, and possible sub-goals are stored. They claim and show that planning happens asynchronously and is determined by the momentary aspects of the problem. No fixed order of operations exists; plan creation and the steps to be taken grow out

of the problem stage at hand. When planners solve a planning problem, they may start with the top-goal, but very soon they loose track of the goal structure and then they continue to fulfill the goals that are reachable within reasonable time. The hierarchy very soon vanishes and what remains is some sort of heterarchy. Therefore, this kind of planning behavior is called opportunistic.

Although the contrast with the hierarchical approach may be large, a strong similarity is also present. In the hierarchical as well as in the opportunistic approach the fundamental assumption is that planning is problem solving, that can best be described in terms of problem spaces, production rules, and goals. That is to say that the basic descriptive structure is the same for both, but that real behavior within the problem space is executed differently.

With regard to the problem space description, hierarchical as well as opportunistic planning differ from the perspective defended by Riesbeck & Schank [9]. The representation of planning problems is described in terms of scripts and frames consisting of objects, slots, and relations. The information in the cognitive system, necessary to make a plan, is semi-hierarchically structured. This means that some kind of representational skeleton or framework is retrieved from memory. Stored plans contain guidelines for resolution of sorts of problems. In this process two stages exist. First a skeleton plan is found, and second the abstract steps in a plan are filled with concrete operations. Although general cognitive processing is involved in making a plan the emphasis in this approach is on the memory system. Plans at different levels of abstraction and in different formats are stored in and retrieved from memory. There are strong similarities with the approach to planning that Hoc proposed [2].

It is very difficult to reveal the different mental representations planners use in solving planning problems. Asking them whether they use production rules or scripts is not reliable and might also give them a cue.

From the above discussions, we derive the following conclusions. Together, the paradigms that were discussed provide various interpretations of a cognitive approach to human planning. In this approach, planning is about how to find the actions that solve a problem or, more general, reach a goal. The process of planning is not neatly hierarchical but switches in level of abstraction and in the time frame under consideration. The process itself is about formulating goals, finding similar solved goals, finding existing plans, adapting plans, and storing plans in such a way that they can easily be found for future reference.

There is another kind of planning that is performed by humans. Instead of planning ones own activities, humans can be involved in coordinating the activities of others. Typically, this takes place in organizations, and we make the shift from planning and executing your own activities to planning of activities that are executed by others.

Humans that plan organizational processes: Planning is a phenomenon that occurs at multiple places in an organization. In its most abstract sense, all activities that involve the determination of the future of the organization are dealing with planning. This includes strategic considerations that determine “where the organization must stand” in 10 years, less abstract issues such as growth targets or product innovations, but also very concrete decisions such as who will work at what time next week, or the exact production times and machine allocations of the production for the following week [10,11]. It is the type of planning about concrete entities that we primarily focus upon. That kind of planning is about coordination of activities of organizational members and the allocation of resources [12]. The types of activities and resources vary widely over organizations. A rough categorization that is based on the things that are planned is the distinction between production planning (machines, orders, machine operators), staff planning (shifts, personnel), and transportation planning (vehicles, routes, chauffeurs, shipments) [13].

Although the variety in organizational planning problems seems large, there are also many characteristics that are shared by organizations. A first generic characteristic for planning problems in organizations is that it basically concerns the coordination of supply and demand, whereby (a) the supply consists of scarce capacity and (b) the way in which this capacity is put to use can make a difference with respect to the goals in the organization [13,14,15]. Examples are producing at low costs at a production facility, having enough phone operators at a call center, or taking care that all employees work the same amount of night shifts. A second shared characteristic is that the planning process is distributed over multiple human planners. This means that plans get made in parallel, and that coordination between the plans is needed. A third shared characteristic for all organizational planning activities is that they are organized hierarchically. Planning problems in organizations are too complex to be solved by one person, so some kind of division in sub-problems is necessary. Therefore, there are approximate plans for the long term and detailed plans for the short term. This induces the need to coordinate; plans at higher hierarchical levels define the decision space for lower hierarchical levels. An example of such a hierarchy is strategic planning versus rough capacity planning versus production scheduling.

Not much literature or theory exists about the relations between the planning domain, the planning task, the organization of the planning, and the performance of plan execution. Most analyses are limited to task models, for example, McKay et al. [16], Mietus [17], Dorn [18], and Sundin [19]. Lack of a theory to explain the relation between planning complexity, planning organization, task performance, and planning support makes it is difficult to pinpoint the cause of the planners’ discontent, to attribute the causes of poor organizational performance to the planning, or to analyze and design planning practices. For example, the cause of poor factory performance can be the mere impossibility of matching

the requirements (e.g., there is not enough capacity available to meet the demands), the clumsiness of the organization of the planning, the inadequacy of the human planner to solve complex problems, the absence of specialized planning support in practice, or a combination of these factors.

In order to make generic statements about the planning task, it is important to know what the task performance depends upon (notice that by performance we mean execution without a qualitative connotation). According to Hayes-Roth & Hayes-Roth, the determinants of the planning task are problem characteristics, individual differences, and expertise [5]. That the task performance depends on individual differences and expertise is no surprise. This applies to all tasks. But the fact that the task performance also depends on problem characteristics leads to the statement that it is possible to describe a planning problem, at least partly, independent from the planner.

Clearly, approaches of planning your own activities deal with other questions than approaches for organizational planning. In section 3, we will analyze in what way planning of organizations differs from planning of your own actions. First, however, we will look at planning by artificial agents.

Artificial agents that plan their own activities: Artificial agents such as (simulated) robots that plan their own behavior need to be able to deal with uncertainty and incomplete information in their task environment. For such agents, planning is a means to reach the goal, just as it is with human problem solving. Due to the close resemblance of human and artificial agents, planning of artificial agents is very much related to the problem solving approaches as described earlier. Techniques from Artificial Intelligence are used to let such agents function more or less independently in their environment, and react on unforeseen events [20,21,22]. Much of the planning research in Artificial Intelligence stems from the wish to let autonomous actors or agents (such as robots) perform tasks without prescribing how the task should be carried out [23]. Most Artificial Intelligence methods, whether they are called algorithms, procedures, or heuristics, are based on state space descriptions. An agent or actor finds himself in a state, in which it can perform a limited number of actions. An action changes the state, after which it can again perform a number of actions [24]. The agent keeps on choosing and performing actions until the state it gets in somehow satisfies its goal. Planning is one way in which the agent can reach its goal. Other ways are, for example, trial and error or full search. To make a plan, an agent somehow anticipates the future by simulating the actions he will make. This requires the existence of (internal) representations. The original link to physical entities has been relinquished somewhat so planning agents are now often only computer programs that find a plan merely for the sake of research, and therefore not necessarily execute it. In this paradigm, planning is searching for a sequence of actions that will bring the agent from its current state in the goal state. Models of human problem solving, which were discussed in the previous subsection, have provided researchers in Artificial Intelligence with starting points for the planning functions of their artificial agents. Many examples are based on the initial General Problem Solver (GPS) of Newell & Simon [3], which constructs a proposed solution in general terms before working out the details, the opportunistic planning paradigm, and script-based planning. Here it becomes clear that models of human problem solving are closely related to the anticipation and planning of artificial agents.

Machines (computers) that plan organizational processes: A lot of planning research deals with automatically finding (or generating) plans for future organizational processes. Usually, this is about making a quantitative model that can search efficiently for good solutions. At first glance, the same kind of reasoning is used as in cognitive sciences: a problem space is set up and the aim is to find a state that satisfies all constraints and scores well on goal functions. The states are (just like in the cognitive problem solving approaches) transformed by operators. The difference is that states and operators comprise something else than the ones in cognitive science, namely values on variables and mathematical operations [25].

Models exist for all kinds of processes such as routing of trucks, staff scheduling, job shop scheduling [26,27], and flow shop scheduling. Some of the scientific fields that deal with this kind of research are Operations Research (e.g., linear programming, nonlinear programming, all kinds of heuristics), and Artificial Intelligence (constraint satisfaction programming, genetic algorithms). Although the approaches of course differ, they also possess common characteristics. They are based on an analysis of the entities that are scheduled. For example, to make an algorithm for a planning problem in a flow shop one must know the capacities of machines, setup- and cleaning times, the number and sizes of orders, the processing characteristics, etc. All these characteristics can be used to determine the best way to navigate through the problem space of possible solutions. An example of how such knowledge can be used in an algorithm is to start to plan on the bottleneck first, because it is often the sensible thing to do in order to avoid problems in a later stage of the planning process. Most techniques are somehow limited in the kinds of characteristics that they can handle. For example, a linear programming model cannot deal with nonlinear constraints, and temporal reasoning is tacky to implement in many mathematical techniques. Therefore, the domain analysis must be translated in the quantitative model, and the solution must be translated back to the application domain [28].

Computer programs that create schedules are rarely used on their own. The fact that information is lost during abstraction and translation of the domain into the model is widely recognized. For that reason, mathematical solution techniques are usually used in the context of decision support systems, where a planner can manipulate and change a plan manually so he is not bound to the solution that is presented by

an algorithm.

As with the distinction between humans that plan for themselves and humans that plan for organizational processes, the approaches that deal with computer programs that plan for their own actions differ from approaches that deal with computer programs that plan for organizational processes. The differences have to do with the characteristics of the actors and will be analyzed in the next section.

3. ANALYSIS OF THE PLANNING ACTORS

In section 2, we discussed four topics that are relevant for planning in general: (1) an entity must make the plan, (2) an entity must execute it, (3) the entity that makes the plan must have a model of the future, and (4) the plan exemplifies the ability of the planning entity to use the model of the future to lead the executing entity to the goal state. We now have nearly all the ingredients available to make a reasonable comparison between the different perspectives on planning. The goal of this comparison is to gain insight in the limitations that the approaches for the respective perspectives have and to see where those limitations come from. In the end, this should lead to a better understanding of the "planning" phenomenon, and perhaps the respective approaches can learn from each other. In section 2, we used topics 1 and 2 to describe four distinct planning areas. Topic 3 and 4 are used to assemble a number of characteristics with which the performance of planning actors can be analyzed and compared. The aspects that will be discussed in detail and that are used for comparisons are: a) the way in which the approaches deal with complexity; b) closed versus open world assumptions; c) the information processing mechanism and its architectural components such as memory and attention; d) the representations; e) communication, meaning, and interpretation; f) the characteristics of coordination; and g) aspects of execution of the plan.

Complexity reduction: Planning problems are assignment problems for which a limited set of structurally similar solutions exist. Theoretically, all solutions of a planning problem can be calculated in order to choose the best solution. Unfortunately, even the most seemingly simple planning problems are transcomputational [29], which means that enumeration of solutions is not practically possible. To overcome this, planning actors must choose a way to somehow look at a limited number of viable solutions. Indeed, many of the differences between the kinds of planning actors (see section 2) can be explained by the way in which they reduce the complexity of their planning problems [7]. Some ways in which a planning actor can deal with the complexity are:

1. *Opportunistic planning*. The planning actor takes decisions without any structure; only momentary aspects matter [5].
2. *Plan partitioning*. Plans are often multi-dimensional. The search space can be limited by first making plans for the individual dimensions, and then putting the plans together [30]. An example is a production plan that coordinates machine operators, machines, and production orders: separate plans can be made to assign machine operators to machines, and orders to the machines.
3. *Multiresolutional planning*. A plan can be made at multiple levels of resolution. The plan at a low level of granulation will have a lower complexity. This plan will constrain the search space of the plan at a higher level of granulation [7], so the total number of to be assessed alternatives is lessened.
4. *Learning*. Different plans can contain similar structures that can be reused in similar circumstances. (The abstract connotation is intended since learning can be based on a wide variety of aspects of the planning process.)

In both plan partitioning and multiresolutional planning, multiple plans are created. This decomposition must be a closed-loop process [7, p 265], i.e., the plans must together provide a complete plan. This is of special interest for multi-agent planning systems (such as an organization), where the plans can be made by different people and the coordination issue arises. Furthermore, each of these multiple plans is a (possibly complex) plan in itself, and can therefore be subject to each of these four strategies recursively.

"Closed world" vs. "open world": Looking from a generic perspective, the planning task itself can be called a synthetic or configuration task. From a task perspective realizing a suitable plan or solving a planning problem requires three nearly decomposable phases. In state space descriptions the first phase is the design of a (complex) initial state, of goal state(s) and of admissible operations to change states. The second phase is given the admissible operations to search for an (optimal) solution. In many cases search does not give an optimal solution. The most one may get is a satisfying solution and even that is often not possible. Then, the third phase starts in which one goes back to the initial state and the admissible operations and changes these in such a way that a solution is found. Formulated in other words, the phases of (1) initial state, (2) search, no solution, and (3a) start again with a new initial state follow the so-called "closed world" assumption. This is the necessary sequence if algorithms are applied. However, there is another way of dealing with the third phase which is more usual, especially if humans have to make a plan. If the second phase does not give an optimal or satisfactory outcome given the constraints and goal functions, the planner already is so much involved in the planning process, that because he has a glimpse of the solution given the constraints, he takes his "idea" of a solution for compelling. He therefore changes the initial state and the admissible operations, that is the constraints, in such a way that they fit the preconceived solution. This order of phases can be named the "open world" approach. It consists of (1) initial state, (2) search including

not finding a real or established fixed solution, and (3b) adjustment of initial state according to the “fixed” solution reality. This sequence of activities is what human planners whether in the industry or doing errands frequently and with great success do, but formalizing such knowledge for use in a computer program or robot seems to be very difficult.

Information processing mechanism and architectural components: An information processing mechanism embodies the way information is selected, combined, created, and deleted. The mechanism itself needs a physical or physiological carrier. Various possibilities are already present, such as the brain as our neurological apparatus, the layered connection system of a chip in a computer, a human individual in an organization, or a group of interconnected individuals in an organization. The most relevant distinction is the one in internal and external mechanism. With internal we mean that there is no direct access to the system from outside. Internally controlled, but not directly visible processes take place in the system. The cognitive system and the chip are internal, but they differ in the sense that the latter is designed which means that its operations are verifiable. External are information processing mechanisms such as groups of individuals or organizations. In other words, the kind of predictive model that is needed to anticipate ones own actions differs from the kind of model that is needed to anticipate actions of others. With respect to planning, this distinction is of course relevant if one realizes that if the plan needs to be communicated, a translation is necessary between the physical carrier and the receiver, which must be reckoned with during planning. This is the case when a planner makes a plan that is executed by others.

An architecture is a set of components of which the arrangement is governed by principles of form or function [21]. A cognitive architecture consists of memory components, of attention processors, of sensory and motor components, and of various kinds of central processors. The division is by function and the components are all implemented in neurological structures in the brain. Two other material structures for architectural layout are the chip and the constellation of a group of individuals. The same kind of components can be discerned for the computer, consisting of memory, sensory and motor components, and central processors. For a group of individuals the architecture is different because the constituting elements are similar as for the individuals, but the roles and tasks are different. Again, the discussion about the character of the architecture boils down to a discussion about internally or externally defined. Internal is the cognitive architecture, whereas chips and groups of people can be dealt with externally.

(Internal) representations: In cognitive science the conceptual framework to deal with representations can be found in the approaches of classical symbol systems, connectionism, and situated action [31,32,33,34,8]. The basic idea is that humans as information processing systems have and use knowledge consisting of representations and that thinking, reasoning, and problem solving consist of manipulations of these representations at a functional level of description. A system that internally symbolizes the environment is said to have representations at its disposal. Representations consist of sets of symbol structures on which operations are defined. Examples of representations are words, pictures, semantic nets, propositions, and temporal strings. A representational system learns by means of chunking mechanisms and symbol transformations [32]. An entity that makes a plan for itself can of course misinterpret its position in the environment, for example because it cannot represent its environment or because it cannot manipulate its representation of the environment adequately. Furthermore, an entity that makes a plan for others can additionally have this problem with respect to the entities that must execute the plan. Representations are also immediately relevant for anticipation. A description of a future state in whatever symbol or sign system is the core of any discussion on anticipation. Rosen, for example, defines an anticipatory system as “a system containing a predictive model of itself and/or its environment, which allows it to change state at an instant in accord with the model’s predictions pertaining to a later instant” [35]. Someone who makes a plan for an organization does not need a model of itself, but a model of others and their environment. This can complicate communication and interpretation of the to be planned system.

Communication, meaning, and interpretation: Communication means the exchange of information between different components. Depending on whether we are talking about internal or external information processing entities, communication means restrictions on the kinds of symbols or signs that are used for the exchange. If we relate this to the before mentioned discussion about representations, the various kinds of signs have different consequences. Clearly, sign notations are more powerful, but also more restricted than sign systems, which in turn are more powerful than just sign sets [36,8,37]. Unambiguous communication requires sign notations, but we know that all communication between humans is not in terms of notations. If computers require sign notations and humans work with sign systems, then if the two have to communicate, the one has to adjust to the other. Until recently, most adjustments consist of humans using notations. Now, interfaces are designed that allow computers to work with less powerful - in terms of semantic requirements -, but more flexible sign systems. This means that computers can deal with ambiguity. For mental activities no explicitness (channels, codes etc.) is necessary; for planning as an external task it is essential.

Coordination: Coordination concerns attuning or aligning various entities that are not self-evident unities. Information processing in a cognitive system is a kind of coordination mechanism (with no direct access). It is internal or mental. The

coordinating processor is cognition itself. No explicit code is necessary. If the code is made explicit and obeys the requirements of a notation, then we can design an artificial intelligent agent that in its ultimate simplicity could be a chip. In case of a set of entities that not by themselves are a coherent unity, various coordination mechanism can be found, such as a hierarchy, a meta-plan, mutual adjustment, a market structure, and many others [38,39]. The important difference with the single agent is that these coordination mechanisms are external and of course with direct access.

Planning, execution and control: Making a plan, executing it, and monitoring its outcomes in reality are valued differently in planning your own actions and in planning actions of others (i.e., organizational processes). The planning in organizations usually is decoupled from the execution of the plan. There are two main reasons why the planner is someone else than the one who executes the plan. First, planning is a difficult job that requires expertise and experience. This is the organizational concept of task division. Second, a planner must be able to weigh the interests of many parties. Therefore, he must have knowledge about things that go beyond the limits of the individual tasks that are planned. The consequence of this decoupling is almost always inflexibility with respect to adaptation. For errand tasks the possible division in terms of sub-tasks may be interesting, but can in reality be intertwined with flexible adaptation after unforeseen events. If the controlling entity is itself a unity, discussions about transfer, communication, sign systems to do the communication, and representations are almost trivial. This does not make the planning task itself simpler; it only prevents the occurrence of ambiguity, interpretation, and meaning variance.

We now have discussed a number of planning approaches in section 2, and a number of generic planning characteristics in this section. Table 1 summarizes the findings. Evidently, measures to relate the performance of an actor to its planning activities are context dependent, because the differences in contexts can make performance measures incomparable. For example, the uncertainty in the task environment of an actor makes it hard to establish a clear cause-effect relation between plan and execution. Still, cross functional analyses add to our understanding of the mono-disciplines, and can help to get a better understanding of the relation between planning and performance.

4. Conclusion

Planning is a much debated, highly controversial, and multi-faceted issue. We stated that various kinds of actors can be discerned: natural, artificial, and collective actors. We also discussed that there is no easy exchange between the various planning approaches. Management and organization, cognitive science, mathematics, artificial intelligence, and economics, although all are discussing important issues in planning, do not start with the same problem formulation. We approached the issue of planning by looking especially at the entity that makes a plan. By looking at the kind of actors, their characteristics, and the level of description of the entities and components involved, we stated that discussions about the relation between planning and performance do not have to end in controversies and avowed misunderstandings. We have sketched the

	Natural actor		**Artificial actor**	
	Self planning	**Organization planning**	**Self planning**	**Organization planning**
Complexity reduction	Plan partitioning; Opportunistic planning; Learning	Plan partitioning; Multiresolutional planning	Plan partitioning; Learning	Plan partitioning
Close vs. open world	Fixing the reality to the solution that is found; reformulate the starting-point		Searching for a solution that fits the (modeled) reality	
Information pro-cessing mechanism	Information processing needs not to reckon with the outside world	Translation of internal internally coded information is necessary	Information processing needs not to reckon with the outside world	Translation of internally coded in-formation is necessary; designed
Architectural components	Neurological: memory structures, attention processors		Electronic: memory structures, attention processors	Program components: procedures, variables
Representations	Self-representation	Representation of others	Self-representation	Representation of others
Communication, meaning, and interpretation		Mostly communication with sign systems or sign sets		Communication with sign notations
Coordination	Only with respect to anticipated actions	Coordination of actions of others	Only with respect to anticipated actions	Coordination of actions of others
Planning, execution, and control	Intertwined	Separated	Intertwined	Separated

TABLE 1: Characteristics of kinds of actors related to what they are planning and for whom

components and ingredients of planning actors and we showed that comparisons can be made and that positions can be clarified.

Are there good reasons to discuss planning issues in greater detail? We think there are two good reasons. The first is that any planning (or weaker: any anticipatory) system ultimately acts in an open world. There is nothing wrong with the closed world assumption, but in the end it is part of an open world. Switching between open and closed worlds is something human information processing can easily do, but it is difficult to get it realized for artificial (software) and collective systems (organizations). The second reason is that whether we like it or not, more and more of our fellow "intelligent" companions are software actors (agents) and we are interacting with them. Artificial and collective actors are also planning, but something seems to be different. This incompatibility cannot be solved by imposing one approach on all kinds of actors. It can only be realized if we know what precisely natural actors do when they make plans.

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